10.5005/jp-journals-10024-2102

ORIGINAL RESEARCH

An *in vitro* Evaluation of Friction Characteristics of Conventional Stainless Steel and Self-ligating Stainless Steel Brackets with different Dimensions of Archwires in Various Bracket–archwire Combination

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ABSTRACT

Aim: The purpose of this research is to compare the frictional attributes of stainless steel conventional brackets and self-ligating stainless steel brackets with different dimensions of archwires.

Materials and methods: The test was carried with two sets of maxillary brackets: (1) Conventional stainless steel (Victory Series), (2) stainless steel self-ligating (SmartClip) without first premolar brackets. Stainless steel, nickel–titanium (NiTi), and beta-Ti which are the types of orthodontic wire alloys were tested in this study. To monitor the frictional force, a universal testing machine (Instron 33R 4467) that comprises 10 kg tension load cell was assigned on a range of 1 kg and determined from 0 to 2 kg, which allows moving of an archwire along the brackets. One-way analysis of variance was used to test the difference between groups. To analyze the statistical difference between the two groups, Student's t-test was used.

Results: For Victory Series in static friction, p-value was 0.946 and for kinetic friction it was 0.944; at the same time for SmartClip, the p value for static and kinetic frictional resistance was 0.497 and 0.518 respectively. Hence, there was no statistically significant difference between the NiTi and stainless steel archwires.

Conclusion: It is concluded that when compared with conventional brackets with stainless steel ligatures, self-ligating brackets can produce significantly less friction during sliding. Beta-Ti archwires expressed high amount of frictional resistance and the stainless steel archwires comprise low frictional resistance among all the archwire materials.

Clinical significance: In orthodontics, frictional resistance has always had a major role. Its ability to impair tooth movement leads to the need for higher forces to move the teeth and it extends the treatment time which results in loss of posterior anchorage. Friction in orthodontics is related with sliding mechanics when a wire is moving through one or a series of bracket slots.

Keywords: Beta-titanium archwires, Self-ligating brackets, Stainless steel brackets, Universal testing machine.

How to cite this article: Sridharan K, Sandbhor S, Rajasekaran UB, Sam G, Ramees MM, Abraham EA. An *in vitro* Evaluation of Friction Characteristics of Conventional Stainless Steel and Self-ligating Stainless Steel Brackets with different Dimensions of Archwires in Various Bracket–archwire Combination. J Contemp Dent Pract 2017;18(8):660-664.

Source of Support: Nil

Conflict of Interest: None

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INTRODUCTION

Friction is the tendency to resist motion when a solid is moved tangentially with respect to the surface of another contacting solid. When two contacting surfaces are in motion, three force components come into play, the first is the force responsible for the motion, the second is the frictional force, i.e., in opposite direction to the first force and resists the motion, and the third component is the normal force, which is perpendicular to the contacting surfaces and also to the frictional and moving forces. The amount of friction produced is proportional to the normal force that pushes the two surfaces together.[1,2]

During mechanotherapy, friction at the bracket–archwire interface may interfere with optimal orthodontic tooth movement as some amount of applied force is lost to overcome friction. Frictional force is directly proportional to the applied force[3] and it acts perpendicular to the sliding direction on the archwires through the elastic modules or the metal ligatures that are used to tie them in the bracket slot. Therefore, an understanding of concepts to overcoming friction is necessary to produce tooth movement using appropriate magnitude of force.[4] Frictional force is usually expressed as a product of the coefficient of friction by normal force,[5] i.e., FR = μFn. The frictional force is proportional to normal force when two materials are sliding against each other, which means the coefficient of friction is a constant. The frictional force is independent of the area of contact and sliding velocity of the two objects.

As movement of teeth is not a continuous process, the friction at the interface between bracket–archwire which occurs at the initial movement of teeth will be recorded as static friction. A "static frictional force" is the smallest force needed to start the motion, whereas a "kinetic frictional force" is the force needed to resist the sliding motion of one solid object over another at a constant speed. Friction has always played a key role in orthodontics. Many studies have evaluated the factors that influence frictional resistance. The factors associated with friction include bracket and wire materials, surface conditions of archwires and bracket slot, wire cross section, torque at the wire–bracket interface, type and force of ligation, interbracket distance, saliva, and influence of oral functions.[6-9]

The current study was undertaken to compare the friction between stainless steel conventional brackets and self-ligating stainless steel brackets, and to compare the magnitude of difference of friction in various bracket–archwire combinations.

MATERIALS AND METHODS

This study was performed in the Department of Orthodontics and Dentofacial Orthopedics, Sri Siddhartha Dental College, Tumkur, India, in association with the Research Laboratory, 3M Unitek, Electronic City, Bengaluru, India, using a universal strength testing machine (Instron 33R 4467). The friction was tested in wet conditions using artificial saliva.

The direction of friction is tangential to the common boundary of the two contacting surfaces. As the contact surfaces slide against each other, two components of force arise: The normal force component (N) which is perpendicular to the contacting surface and to the frictional force component and the frictional force component (F).

Frictional force is directly proportional to the normal force, such that F = μN, and μ = coefficient of friction.

Brackets

Two sets of maxillary brackets were tested without first premolar brackets:

1. Conventional stainless steel (Victory Series, 3M Unitek, 0.022″ slot, MBT prescription)
2. Stainless steel self-ligating (SmartClip, 3M Unitek, 0.022″ slot, MBT prescription).

Wires

Three types of orthodontic wires were tested:

1. Stainless steel of 0.016″, 0.017 × 0.025″, and 0.019 × 0.025″ cross sections
2. Nickel–titanium of 0.016″, 0.017 × 0.025″, and 0.019 × 0.025″ cross sections
3. Beta-Ti of 0.016″, 0.017 × 0.025″, and 0.019 × 0.025″ cross sections.

Brackets with 0.022″ slot were tested with each type of wire alloys of 0.016″, 0.017 × 0.025″, and 0.019 × 0.025″ cross sections. Three sets of brackets (central incisor to molar tube with first premolar missing) mounted on acrylic plate with the help of preformed jig were used for stainless steel, NiTi, and beta-Ti archwires.

A universal testing machine (Instron 33R 4467) with a 10 kg tension load cell, set on a range of 1 kg and calibrated from 0 to 2 kg, was used, which allows sliding of an archwire along the brackets and recording of the frictional forces. As movement of teeth is not a continuous process, the friction at the bracket–archwire interface which occurred at the initial movement and after attaining the constant speed was recorded. This study was conducted in wet conditions using artificial saliva. The saliva was dripped continuously onto the archwire–bracket couple with the help of a peristaltic pump at a flow rate of 3 mL/min. Each type of archwire that was attached to the crosshead of the testing machine moved through the brackets at a rate of 2.5 mm/min, for 2 minutes. A custom-made mounting jig of acrylic with metal holdings was prepared to suit the Instron testing machine. Straight lengths of wire to be tested were fitted to the bracket slot and were passively ligated to the tie wings using elastic ligatures for conventional stainless steel brackets and by closing the cap for self-ligating brackets. The movement of the wire, which is attached to the crosshead, was stopped after initial movement of the bracket and initial resistance to the movement was considered as static friction. After each test, the bracket and wire assembly was changed and the process is repeated.

Statistical Tests

For data entry and analysis, Excel and Statistical Package for the Social Sciences (SPSS Inc., Chicago) software packages were used. The results were averaged (mean ± standard deviation) for each parameter and are presented in Tables 1 to 4 and Figures 1 and 2.

One-way analyses of variance were used to test the difference between groups. The Student's t-test was used to determine whether there was a statistical difference between the two groups in the parameters measured. In the above test, $p < 0.05$ was accepted as indicating statistical significance.

RESULTS

Post hoc pair-wise comparison showed higher static and dynamic friction in beta-Ti wires with all bracket types as compared with stainless steel and NiTi wires, and the values were statistically insignificant. For Victory Series in static friction, p-value was 0.946 and for kinetic friction it was 0.944; at the same time for SmartClip, the p value for static and kinetic frictional resistance was 0.497 and 0.518 respectively. The values suggest no significant differences

Table 1: Static frictional force of different archwire materials

Material	*Mean static*	*SD*	*Min*	*Max*	*f-value*	*p-value*
Victory						
Stainless steel	161.489	114.37215	44.986	273.604	0.056	0.946
NiTi	165.74467	106.12736	60.321	272.562		
Beta-Ti	189.065	105.13231	88.369	298.133		
SmartClip						
Stainless steel	47.98633	39.239113	11.269	89.336	0.787	0.497
NiTi	61.644	41.894802	18.557	102.235		
Beta-Ti	105.51867	83.933398	21.954	189.816		

SD: Standard deviation

Table 2: Kinetic frictional force of different archwire materials

Material	*Mean kinetic*	*SD*	*Min*	*Max*	*f-value*	*p-value*
Victory						
Stainless steel	140.82533	101.29978	38.786	241.369	0.058	0.944
NiTi	148.60133	101.97584	48.003	251.901		
Beta-Ti	167.744	94.949179	81.569	269.532		
SmartClip						
Stainless steel	41.827	35.134132	8.003	78.139	0.736	0.518
NiTi	51.72567	40.531943	12.123	93.127		
Beta-Ti	91.87433	75.569304	18.369	169.351		

SD: Standard deviation

Table 3: Static frictional force of different cross sections of archwires

Material	*Mean static*	*SD*	*Min*	*Max*	*f-value*	*p-value*
Victory						
0.016"	64.55867	21.99976	44.986	88.369	136.595	<0.001
0.017 × 0.025"	170.307	9.026844	164.351	180.693		
0.019 × 0.025"	281.433	14.47201	272.562	298.133		
SmartClip						
0.016"	17.26	5.459301	11.269	21.954	6.8	0.029
0.017 × 0.025"	70.76	31.24646	43.354	104.786		
0.019 × 0.025"	127.129	54.67029	89.336	189.816		

SD: Standard deviation

Table 4: Kinetic frictional force of different cross sections of archwires

Material	*Mean kinetic*	*SD*	*Min*	*Max*	*f-value*	*p-value*
Victory						
0.016"	56.11933	22.51671	38.786	81.569	120.622	<0.001
0.017 × 0.025"	146.784	4.964385	142.321	152.131		
0.019 × 0.025"	254.2673	14.22984	241.369	269.532		
SmartClip						
0.016"	12.83167	5.219209	8.003	18.369	7.445	0.024
0.017 × 0.025"	59.05633	25.53672	39.339	87.903		
0.019 × 0.025"	113.539	48.91211	78.139	169.351		

SD: Standard deviation

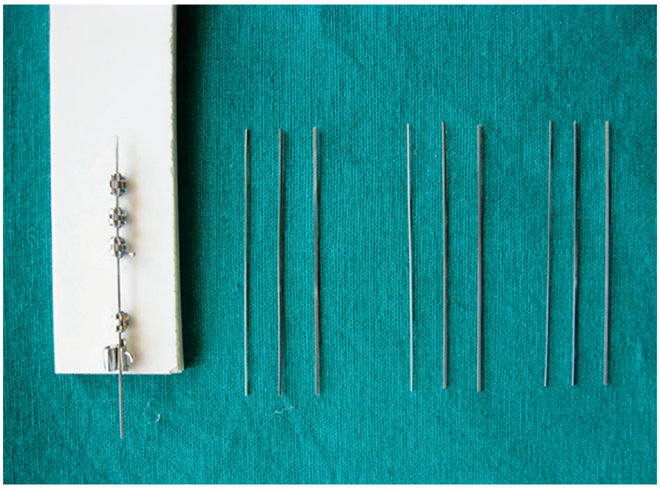

Fig. 1: Different orthodontic wire alloys used in this study

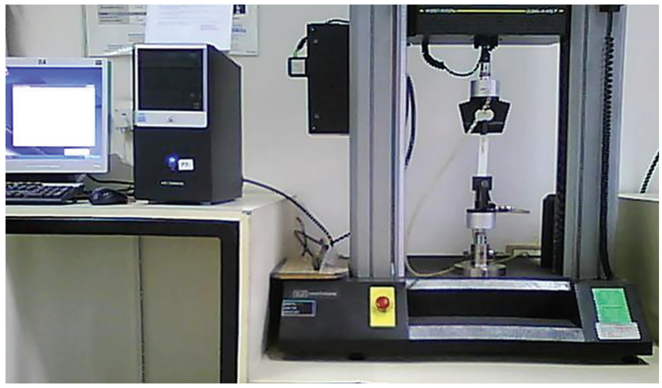

Fig. 2: A universal testing machine (Instron 33R 4467)

between NiTi and stainless steel archwires for static and kinetic friction in Victory Series as well as SmartClip brackets. The results are shown in Tables 1 and 2. Tables 3 and 4 shows the static and kinetic frictional force of different cross sections of archwires. With SmartClip brackets, the results were statistically significant for static (0.029) as well as kinetic (0.024) frictional force.

DISCUSSION

Literature states that the material properties of the bracket, wire, and ligature play an important role in the amount of friction generated. Effective tooth movement can occur only when applied forces adequately overcome the friction at the bracket–wire interface. Binding of bracket on guiding archwire occurs through a series of tipping and uprighting during tooth movement, and though it creates friction, it signifies orthodontic tooth movement.

The static and kinetic frictional forces should be minimized to improve efficiency of mechanics and obtain optimal tooth movement. The present study was conducted to evaluate the effect of mechanical factors that are bracket type, archwire material, and archwire size on the friction produced in wet conditions.

Shivapuja and Berger[10] and Cacciafesta et al[3] concluded that use of self-ligating brackets resulted in less friction when compared with conventional brackets tied with elastomeric ligatures. In the present study, we have obtained the results which were similar to the results of the study by Thorstenson GA et al,[14] as similar protocol of self-aligning model was used. However, studies performed by Loftus et al[5] revealed no significant difference in frictional forces of self-ligating brackets and conventional brackets. The reason was that, in the initial stages of alignment, the major part of friction is due to the binding of the archwire, and hence, friction was same for both the groups. Thorstenson and Kusy[11] changed the angulation and got different results than our study. In the present study, the brackets were set up so that they would self-align, which might be the reason for these conflicting results.

Self-ligating brackets have been known to produce less friction compared with conventional brackets since they do not require ligation. They have a built-in clip that can be closed to form the labial surface of the slot, which creates passive ligation of the archwire. The reduced friction characteristics of self-ligating brackets are more pronounced when brackets are well aligned as in the present study. If a bracket is tipped mesiodistally, the archwire will contact the occlusal and gingival corners of the slot, which will result in binding of the wire. If binding is present, the friction markedly increases regardless of the method of ligation.[11,12]

To increase the value of translational meaning of *in vitro* studies to *in vivo* situations, previous studies incorporated lubricants, such as silicone or Ringer's solution combined with glucose. However, the most frequently used lubricant is artificial saliva.[13,14]

In this study, frictional forces were measured in the wet state to simulate the oral conditions. Artificial saliva as a lubricant might best simulate the situation in the oral milieu. Tselepis et al[13] reported that lubrication with artificial saliva resulted in significantly lower frictional values than testing in dry conditions; this finding was valid for nearly all bracket–archwire combinations studied.

Cacciafesta et al,[3] Downing et al,[15] Taylor and Ison,[16] and Kapur et al[17] found the static friction force to be always higher than dynamic friction. The present study also showed the similar results for any given archwire, bracket, and cross section. The reason behind these results is related to the initial binding of the archwire in the bracket slot denoting static friction much higher than the kinetic friction.

The present study showed that the wire alloys significantly influenced friction. The results showed that friction generated by beta-Ti archwires was greater than stainless steel and NiTi archwires for all bracket–archwire combinations. These findings are similar with results from various studies reported in the past.[5,18,19] The possible explanation for the increased friction with beta-Ti wires might be higher adherence of the wire material to the material of the bracket slot during the experiment. No significant differences were found between NiTi and stainless steel archwires. This finding is similar with the findings of Loftus et al.[5] However, previous studies[7,13] in which the frictional resistance of those two alloys was compared have had conflicting results. Some studies[7,13] showed greater frictional forces with stainless steel wires and with NiTi archwires. This variability was probably due to differences in experimental designs and variations in bracket wire angulations, which in many studies was not zero.

It has been demonstrated that archwire size, shape, and material properties contribute to the magnitude of friction generated; smaller wires tend to produce less friction as they have more clearance in the slot of the bracket and they have greater elasticity as compared with larger wires.[20]

Iwasaki et al[21] and Braun et al[22] in their studies have revealed that though masticatory forces reduced frictional resistance, the effect was unpredictable and inconsistent.

In our present study, we have not considered the effect of masticatory forces over binding of the archwire, saliva, plaque, acquired pellicle, corrosion, food particles, bracket dimensions, and torque at the bracket–archwire interface, which can be considered as the shortcomings of our study.

CONCLUSION

This study concluded that, self-ligating brackets can produce significantly less friction when compared with conventional brackets with stainless steel ligatures during sliding. Beta-Ti archwires expressed the maximum amount of frictional resistance and the stainless steel archwires had the lowest frictional resistance. Magnitude of friction can be concluded to be directly proportional to the cross section of the archwire. Static frictional forces were always greater than dynamic friction with all archwire–bracket combinations and in all the cross sections of the archwires tested in this study.

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